

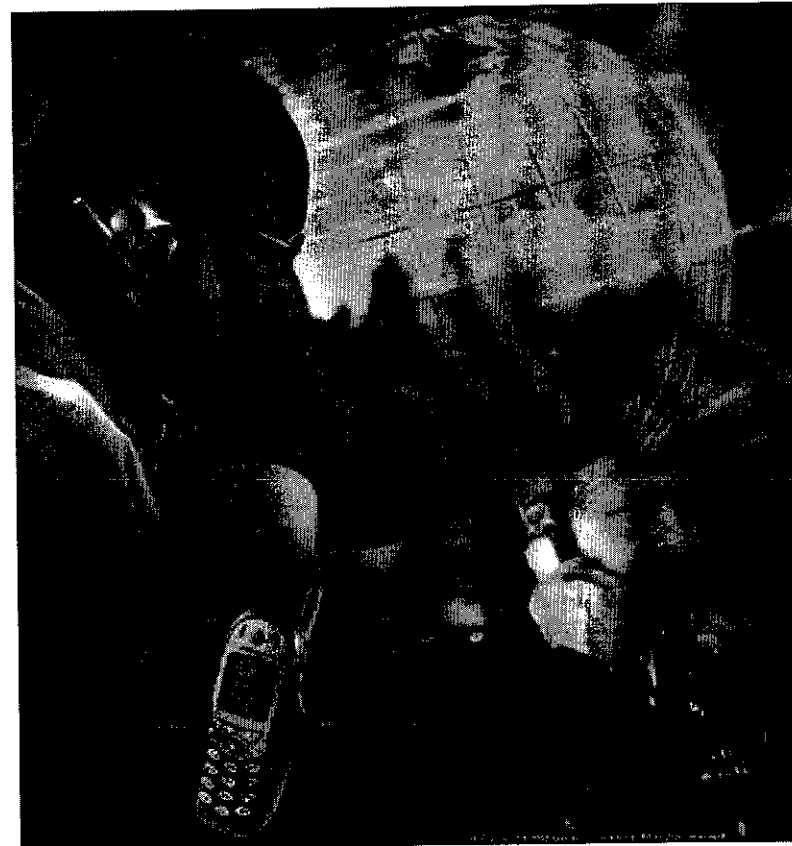
**GENERAL DYNAMICS** RECEIVED

Decision Systems

OCT 21 2003

Federal Communications Commission  
Office of the Secretary**SDR Technology  
Implementation for  
the Cognitive Radio****Bruce Fette PhD***Chief Scientist  
General Dynamics Decision Systems*

bruce.fette@gdds.com

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List A B C D E

2

# **Cognitive Radio\* is Built on SDR\***

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- **We must start with a Software Defined Radio as a basic platform on which to build a Cognitive Radio**
- **Cognitive Radio can provide the spectral awareness technology to support FCC initiatives in Spectral Use**

\*SDR and Cognitive Radio are terms coined by Dr. Joe Mitola - see appendices for references

# Definition of SDR

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- **From FCC NPRM\*:** “We view software defined radios as the result of an evolutionary process from purely hardware-based equipment to fully software-based equipment. In this regard, the process can be roughly described in three stages
  - **1. Hardware driven radios:** Transmit frequencies, modulation type and other radio frequency (RF) parameters are determined by hardware and cannot be changed without hardware changes.
  - **2. Digital radios:** A digital radio performs part of the signal processing or transmission digitally, but is not programmable in the field
  - **3. Software Defined Radios:** All functions, modes and applications can be configured and reconfigured by software.

# Definition of SDR - Continued

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- **SDR Forum:**
  - 4. SW defines all waveform properties, cryptography and applications, is re-programmable, and may be upgraded in the field with new capabilities
- **Importance of Standards (APIs)**
  - 5. HW Interfaces, RF services, Operating Environment, Application to Radio Interfaces

# SDR Technology

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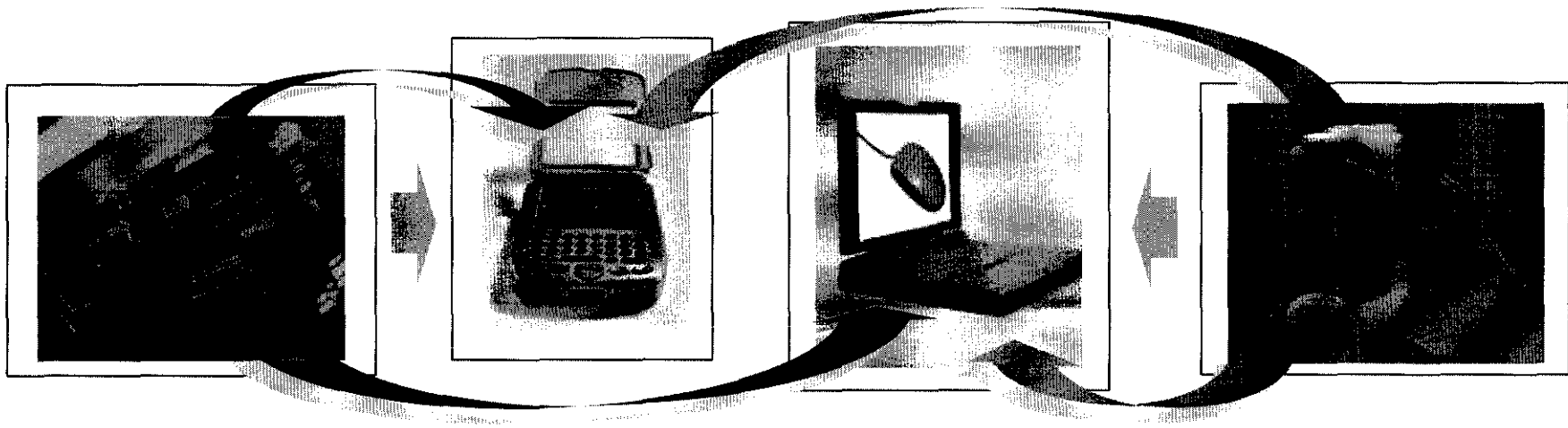
- **Technology fundamentals:**

- Digital Signal Processors (DSPs) provide virtually infinite programmability
- All modulation, cryptography, protocols, and source coding (voice, data, imagery) are established using software
- Many types of modulation can be accomplished over a broad range of frequencies, thereby an SDR is capable of servicing more than one class of service
- Field serviceable, when requirements change, upgrades and modifications are relatively easy to execute

# SDR Standardized Architecture Supports Both Current and Future Applications

- FDMA, TDMA, CDMA, TDD
- AM, FM, MFSK, MPSK, MQAM, CPM, SSB, DSSS ...
- DES, 3DES, AES, MeXe
- Trunked Radio, APCO-25, GSM, Iridium, 802.11..
- Tone Coded Squelch, CVSD, LPC, VSELP, AMBE, ....

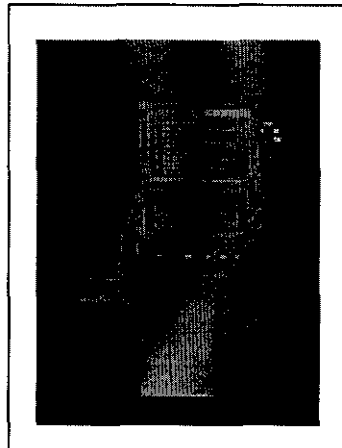
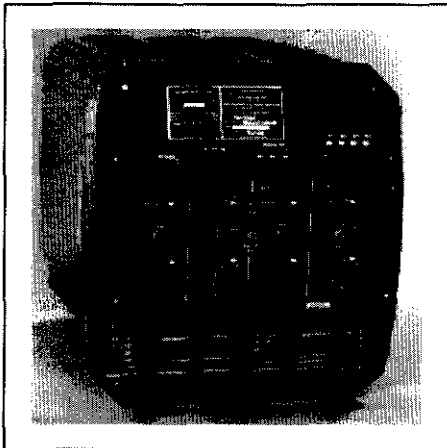
*It's just a matter of software!*



# **Building the Cognitive Radio using SDR Technology**

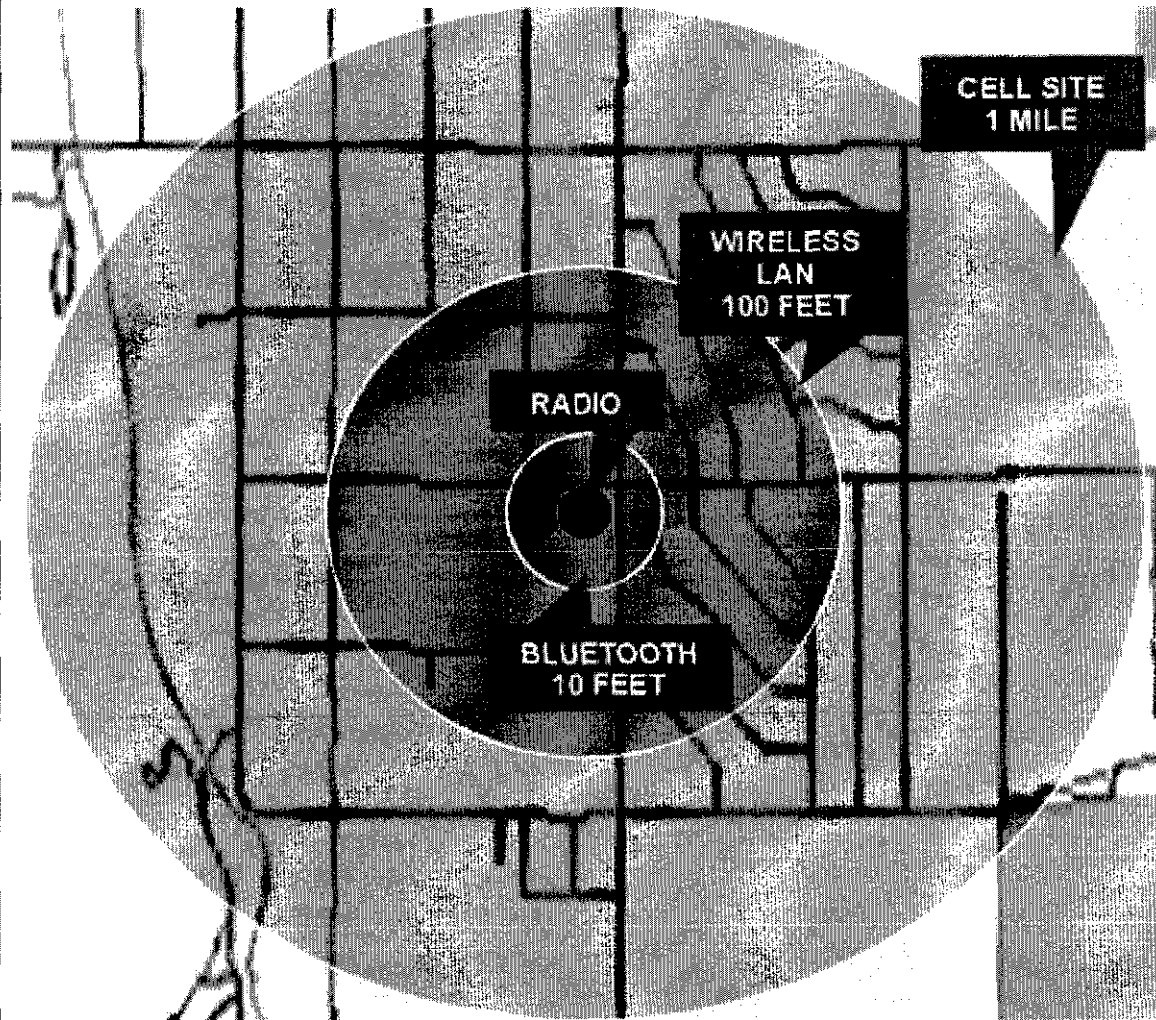
## **- The SDR Radio is Available Now!**

- **SDR drives the Cognitive Radio concept that will provide the spectral awareness technology supporting the FCC's Spectral Use initiatives**
- **SDR is a proven, flexible, COTS technology platform**
- **SDR Technology is in Production and Available Now**



**New  
Announcements  
Coming  
Soon**

# Cognitive Radio Means “Smart” and “Alert”

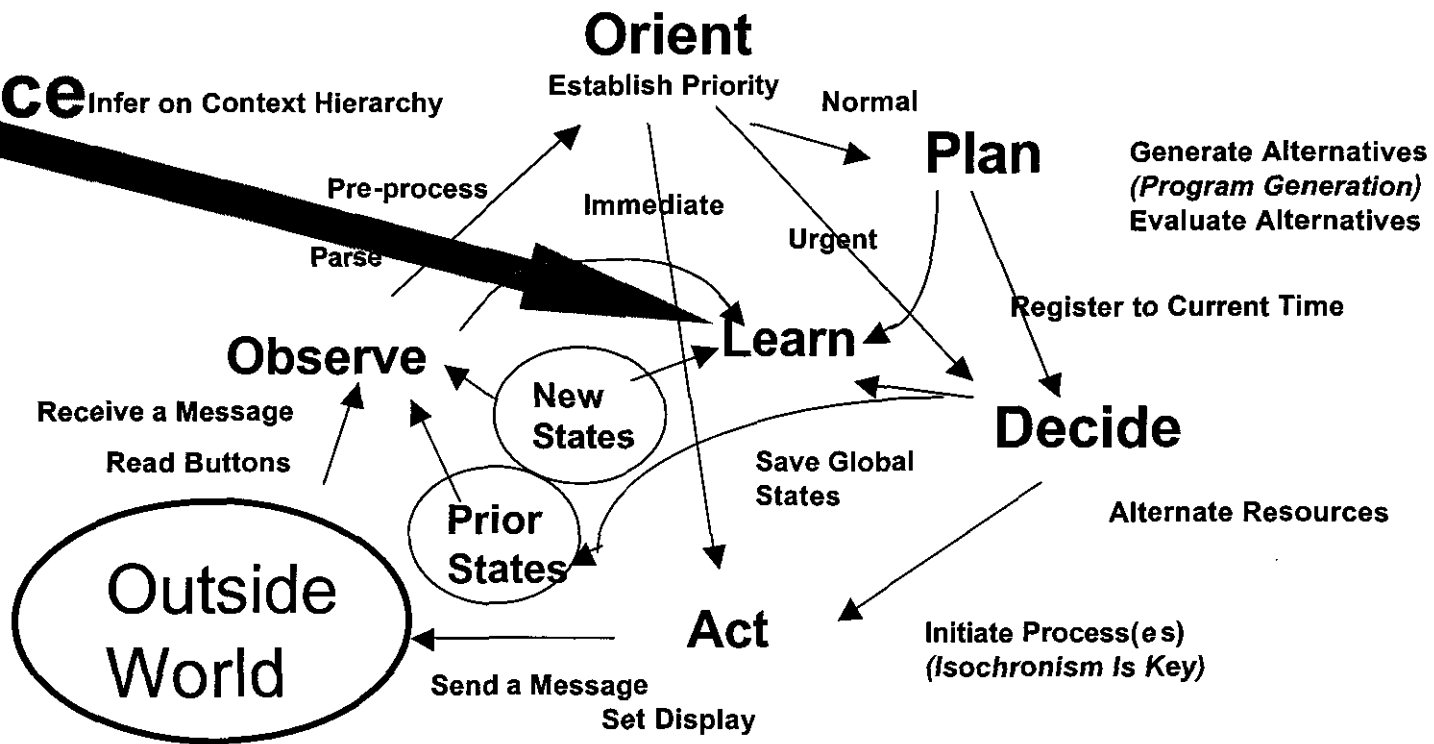


- It knows where it is
- It knows what services are available, for example, it can identify then use empty spectrum to communicate more efficiently
- It knows what services interest the user, and knows how to find them
- It knows the current degree of needs and future likelihood of needs of its user
- Learns and recognizes usage patterns from the user
- Applies “Model Based Reasoning” about user needs, local content, environmental context



# How Does a Cognitive Radio Get So Smart?

**External  
Intelligence  
Sources**



**The Cognition Cycle**

Mitola, "Cognitive Radio for Flexible Mobile Multimedia Communications", IEEE Mobile Multimedia Conference, 1999, pp3-10

# Example Spectral Awareness Etiquette That Can Be Implemented on Existing SDR / Cognitive Radio

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- **Infrastructure Based Approaches**

- Possible Infrastructure Reuse - spread economic support base
- Existing examples of Spectrum sharing Protocols
  - A) Trunked radio
  - B) Cellular spectrum borrowing
  - C) Demand Assigned Multiple Access (DAMA)(demand assigned time sharing)
- Infrastructure Supports wide Range of Spectrum Management Policies
  - Match Requirements, Priorities, Spectral Mask of Owners

# Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

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- Cognitive Radios can adopt new etiquettes for new standards
  - Possible Demonstrations using existing SDRs
    - ✓ Spectrum rental transactions
    - ✓ Spectral Availability (Borrow) Beacon
    - ✓ Local Spectrum Utilization Database Server (time, freq, code, space, power, modulation)

- **Distributed techniques - Possible Demonstrations**

- Spectral Noise temperature (Kolodzy, 2002)
- RTS - CTS handshake (handshake includes local spectral activity model at each end of link, as well as BW, packet size, TX PWR for APC). Minimizes hidden node problem
- Underlay, Overlay, Interweave

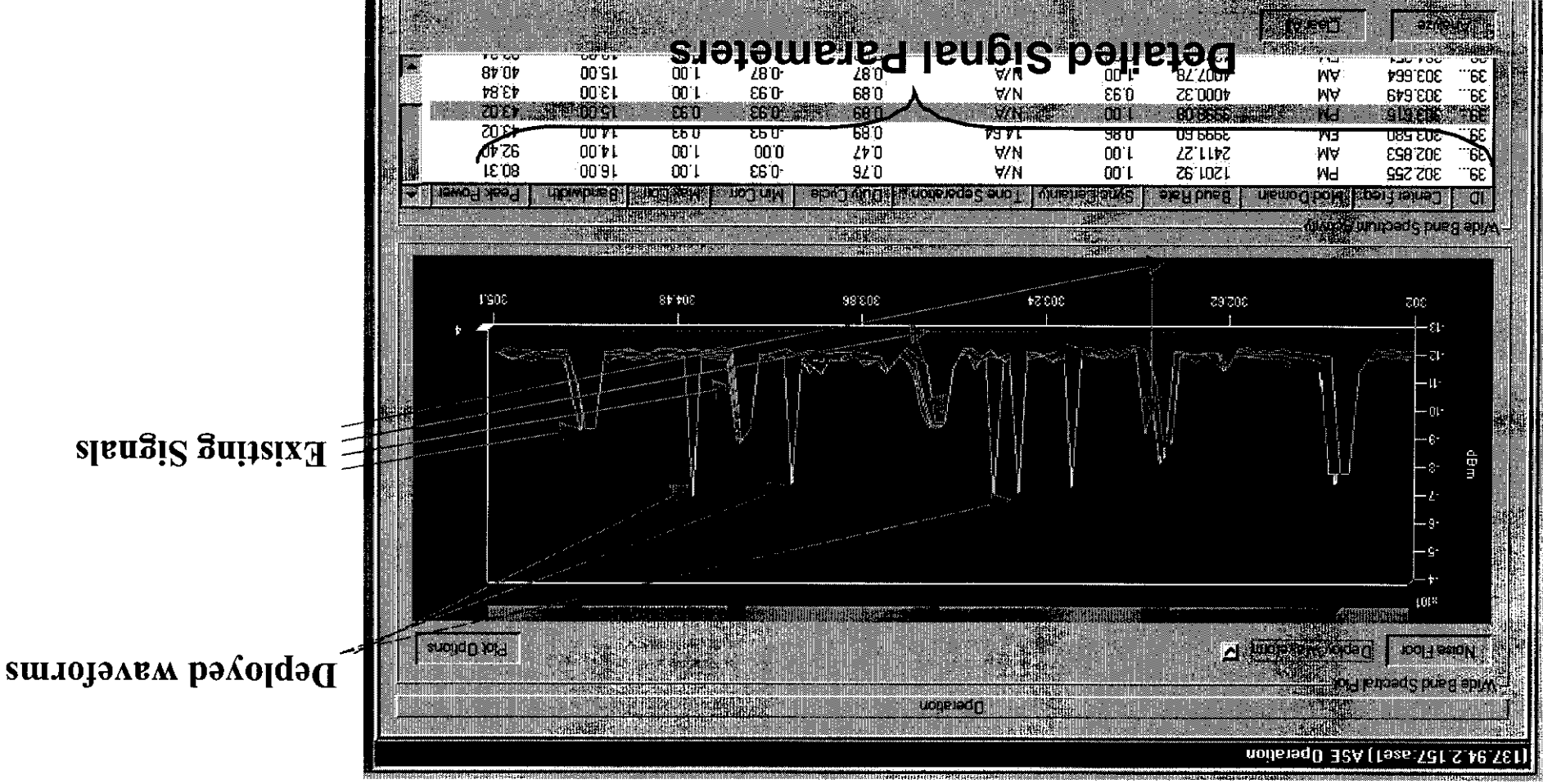
## **Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio** (continued)

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- **Waveform Orthogonality: Time - Freq - Code - Hop/Chirp - Spatial**
  - Usually Involves some form of CSMA sensing for high priority user

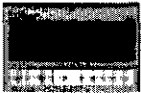
Adaptive Frequency - find a frequency

# SDR Finds Frequency - Time Opportunities Spectral Awareness Etiquette



## Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

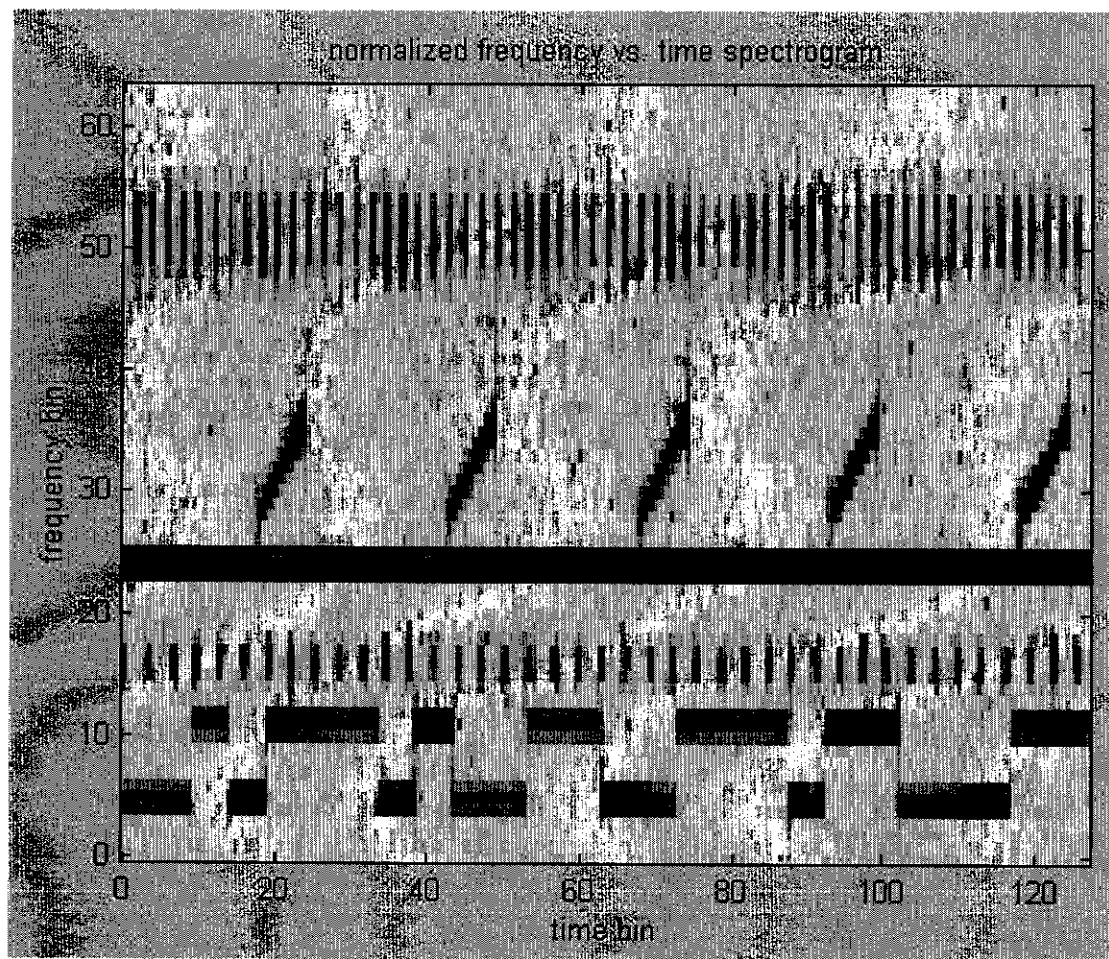
- Waveform Orthogonality: Time - Freq - Code - Hop/Chirp - Spatial
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Adaptive Frequency - find a frequency

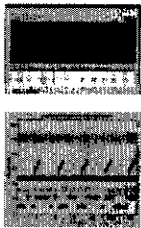
Adaptive TDMA - find an unused time slot in between a periodic user

# Opportunities for Spectral Reuse Amongst Periodic Signals



## Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

- Waveform Orthogonality: Time - Freq - Code - Hop/Chirp - Spatial
  - Usually Involves some form of CSMA sensing for high priority user



Adaptive Frequency - find a frequency

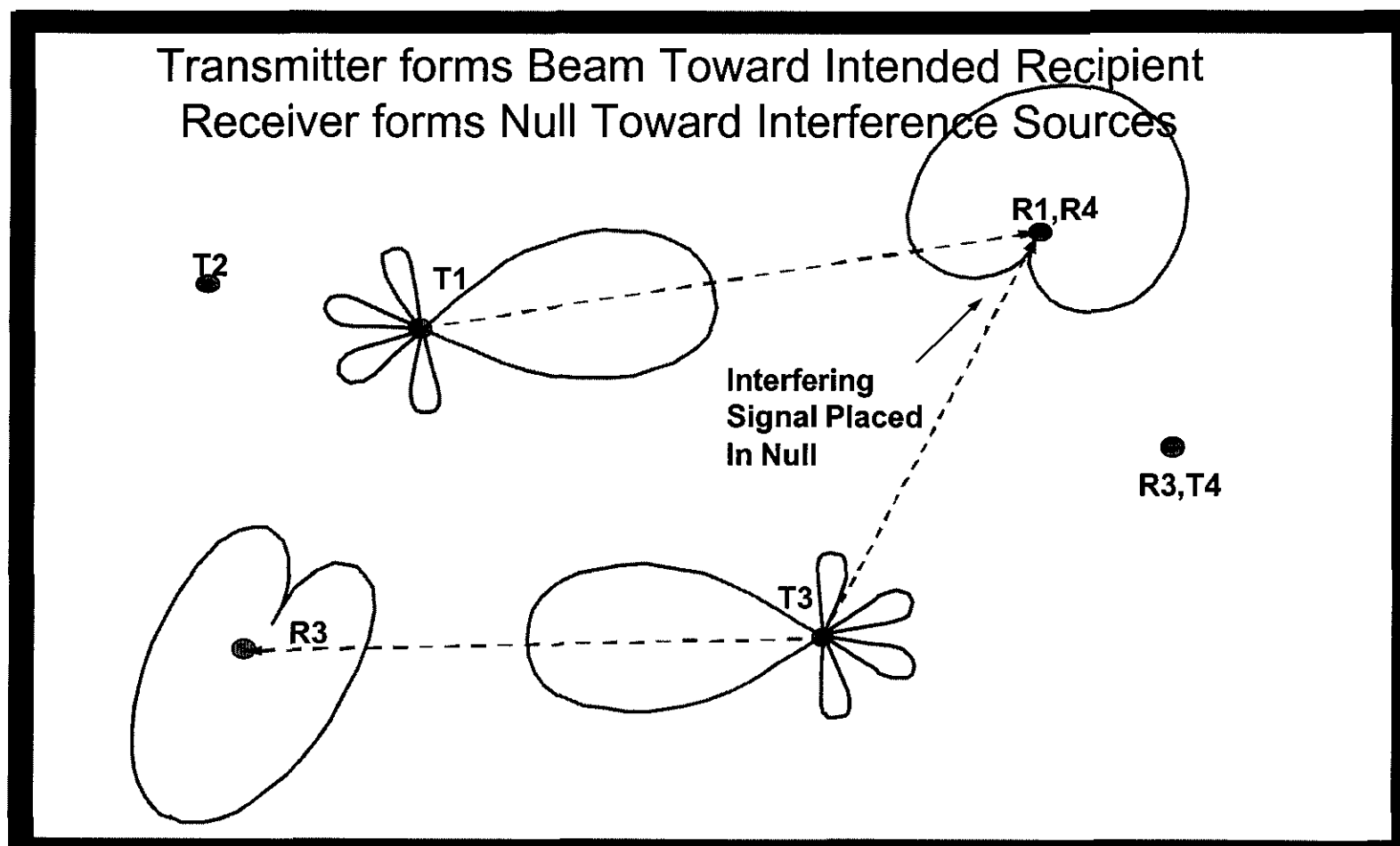
Adaptive TDMA - find an unused time slot in between a periodic user

Spatial - Beam steering and Null Steering



# Time - Frequency - Space

## Each Domain has Opportunities for Spectral Reuse



# Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

- Waveform Orthogonality: Time - Freq - Code - Hop/Chirp - Spatial
  - Usually Involves some form of CSMA sensing for high priority user



Adaptive Frequency - find a frequency



Adaptive TDMA - find an unused time slot in between a periodic user

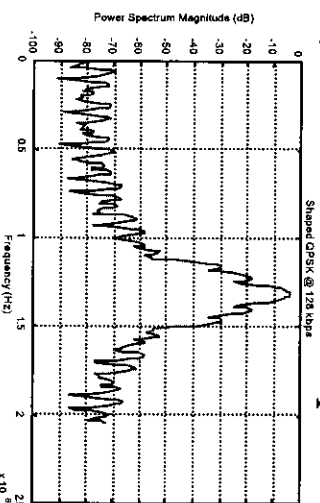


Spatial - Beam steering and Null Steering

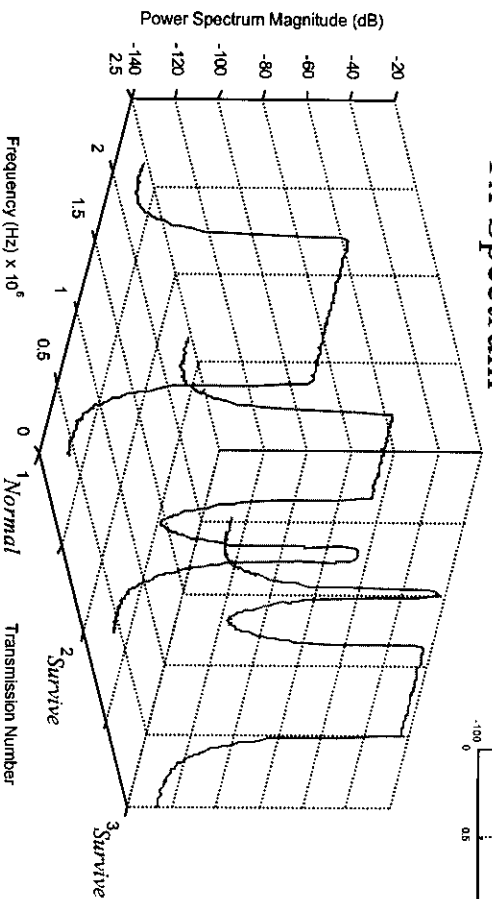
Adaptive Bit Loading onto OFDM carriers based on SNR

# OFDM Interference Avoidance

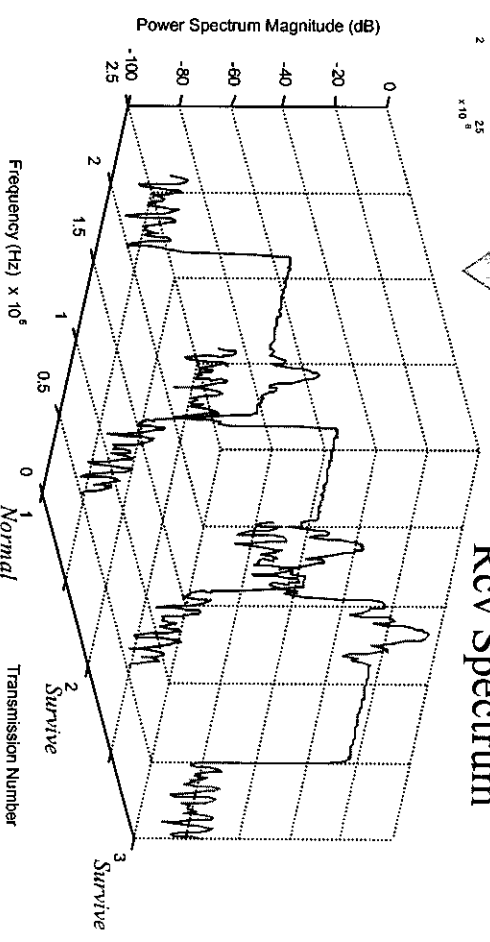
QPSK Interference Spectrum



Tx Spectrum

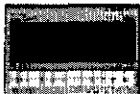


Rcv Spectrum



# Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

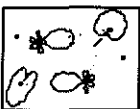
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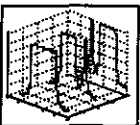
Adaptive Frequency - find a frequency



Adaptive TDMA - find an unused time slot in between a periodic user



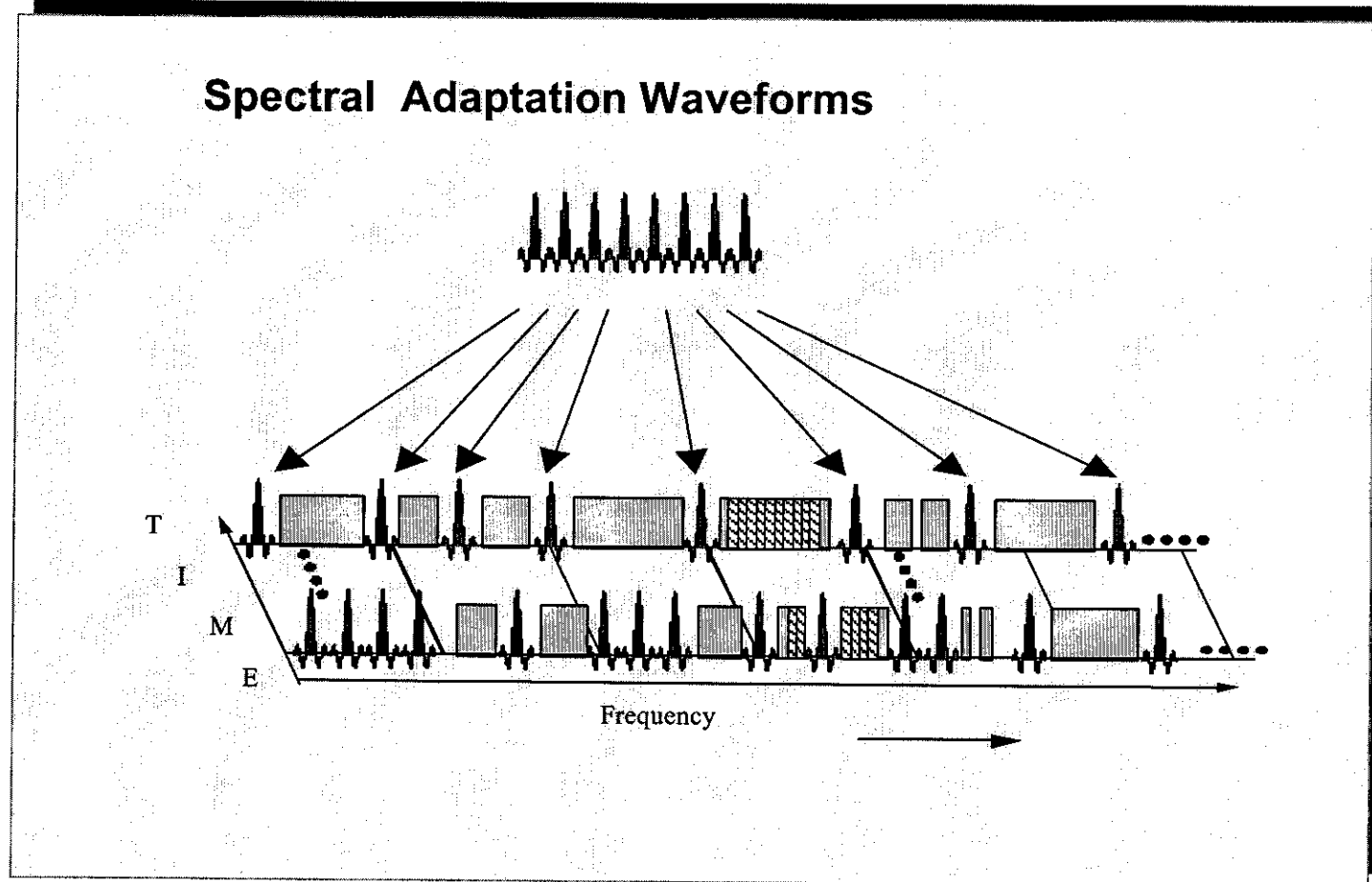
Spatial - Beam steering and Null Steering



Adaptive Bit Loading onto OFDM carriers based on SNR

OFDM techniques where small spectral holes can be filled by one or a few carriers that fit the time - frequency hole

# OFDM Carriers Selected for Use That Fall into Available Spectrum



# Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

- Waveform Orthogonality: Time - Freq - Code - Hop/Chirp - Spatial
  - Usually Involves some form of CSMA sensing for high priority user



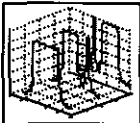
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Adaptive TDMA - find an unused time slot in between a periodic user



Spatial - Beam steering and Null Steering



Adaptive Bit Loading onto OFDM carriers based on SNR

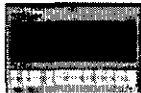


OFDM techniques where small spectral holes can be filled by one or a few carriers that fit the time - frequency hole

Interference Suppression & MultiUser Decomposition

# Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

- Waveform Orthogonality: Time - Freq - Code - Hop/Chirp - Spatial
  - Usually Involves some form of CSMA sensing for high priority user



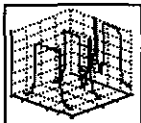
Adaptive Frequency - find a frequency



Adaptive TDMA - find an unused time slot in between a periodic user



Spatial - Beam steering and Null Steering



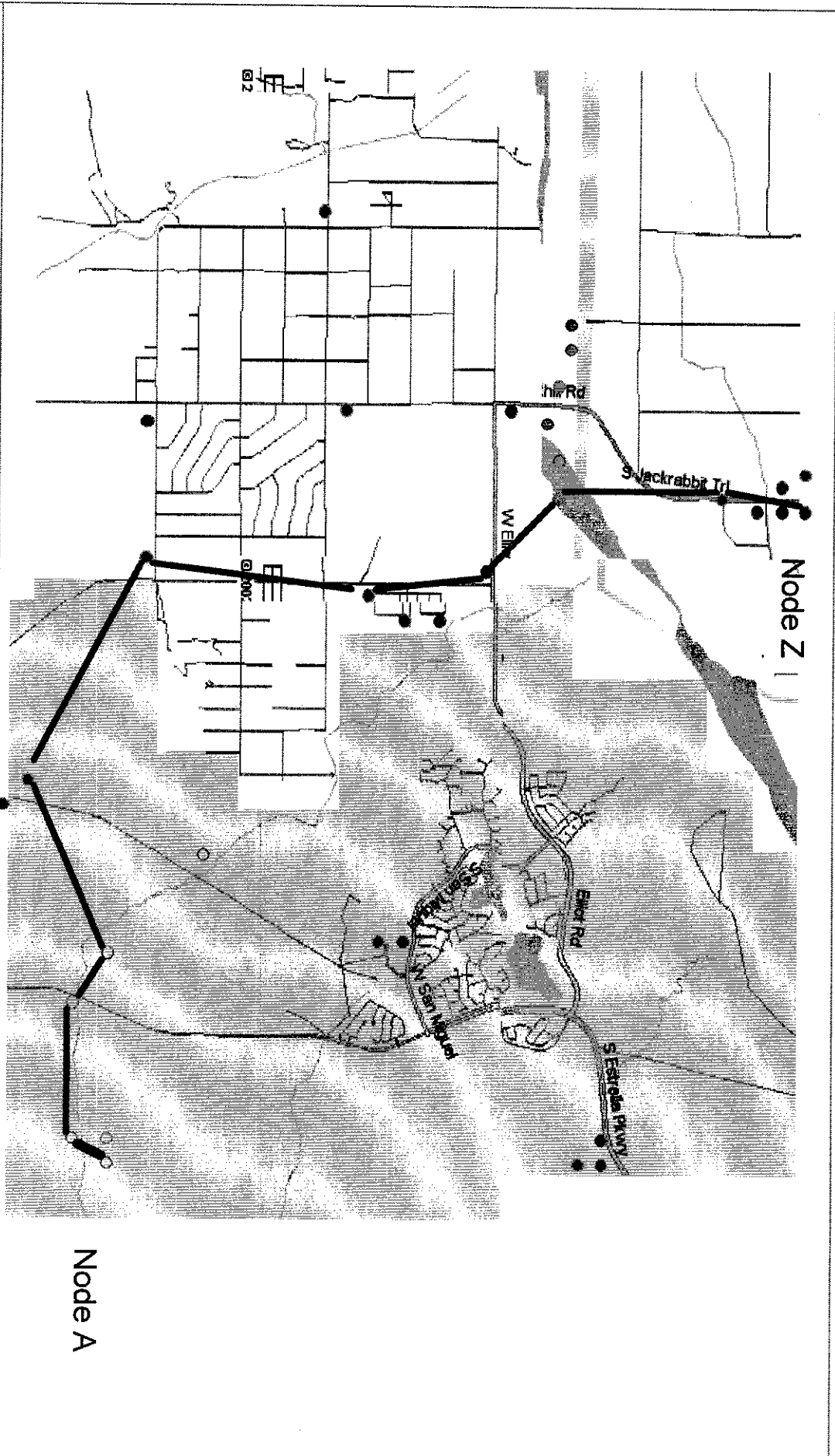
Adaptive Bit Loading onto OFDM carriers based on SNR



OFDM techniques where small spectral holes can be filled by one or a few carriers that fit the time - frequency hole

Interference Suppression & MultiUser Decomposition

- Importance of Adaptive Power Control
- AD Hoc Networking (shortest hop routing w APC)

[illegible]



# Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

- Waveform Orthogonality: Time - Freq - Code - Hop/Chirp - Spatial
  - Usually Involves some form of CSMA sensing for high priority user



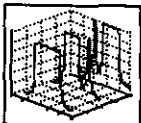
Adaptive Frequency - find a frequency



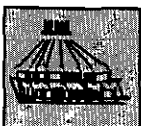
Adaptive TDMA - find an unused time slot in between a periodic user



Spatial - Beam steering and Null Steering



Adaptive Bit Loading onto OFDM carriers based on SNR



OFDM techniques where small spectral holes can be filled by one or a few carriers that fit the time - frequency hole

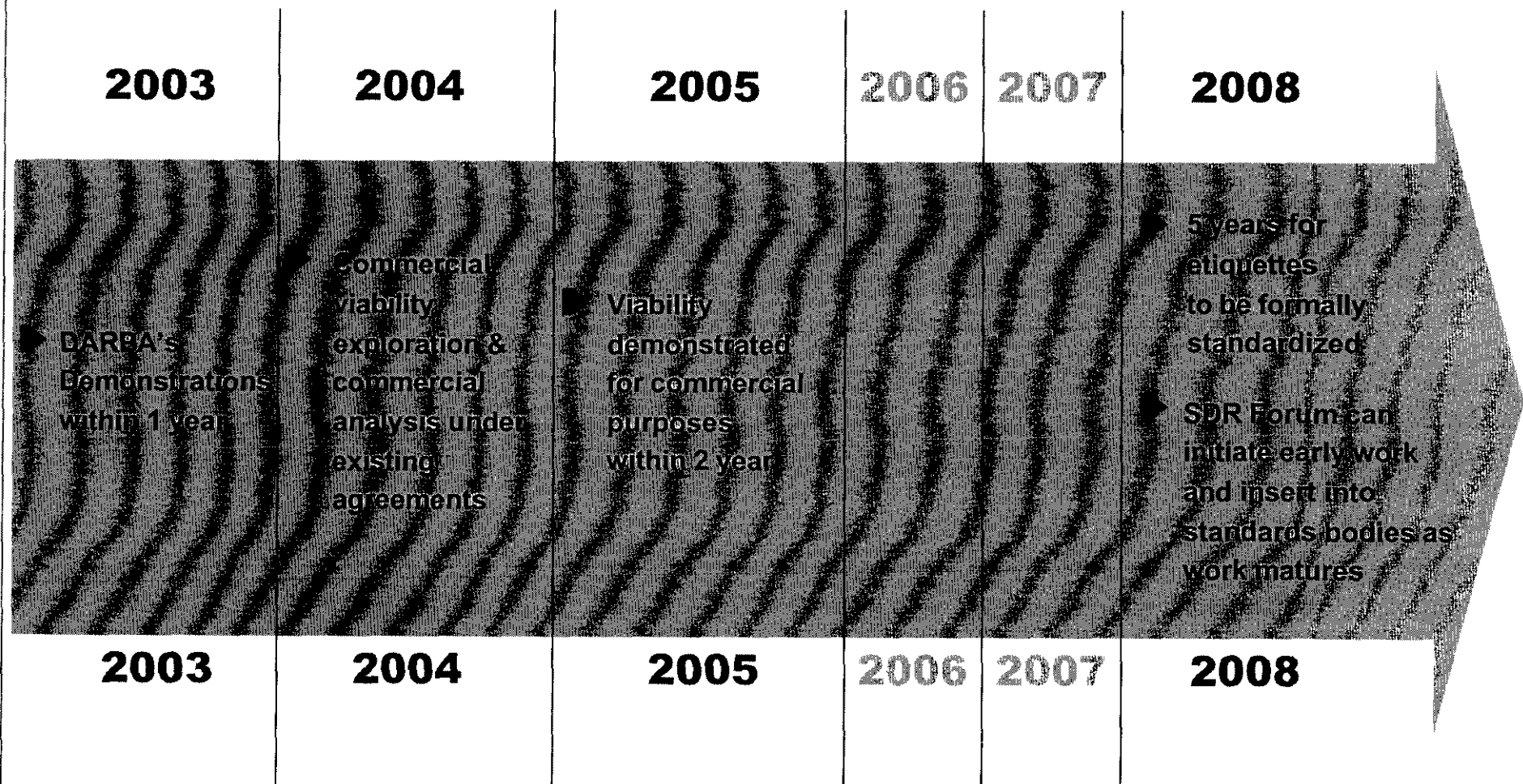


Interference Suppression & MultiUser Decomposition

- Importance of Adaptive Power Control

- AD Hoc Networking (shortest hop routing w APC)

# Timeline: SDR's to have Cognitive Capabilities



# In Conclusion

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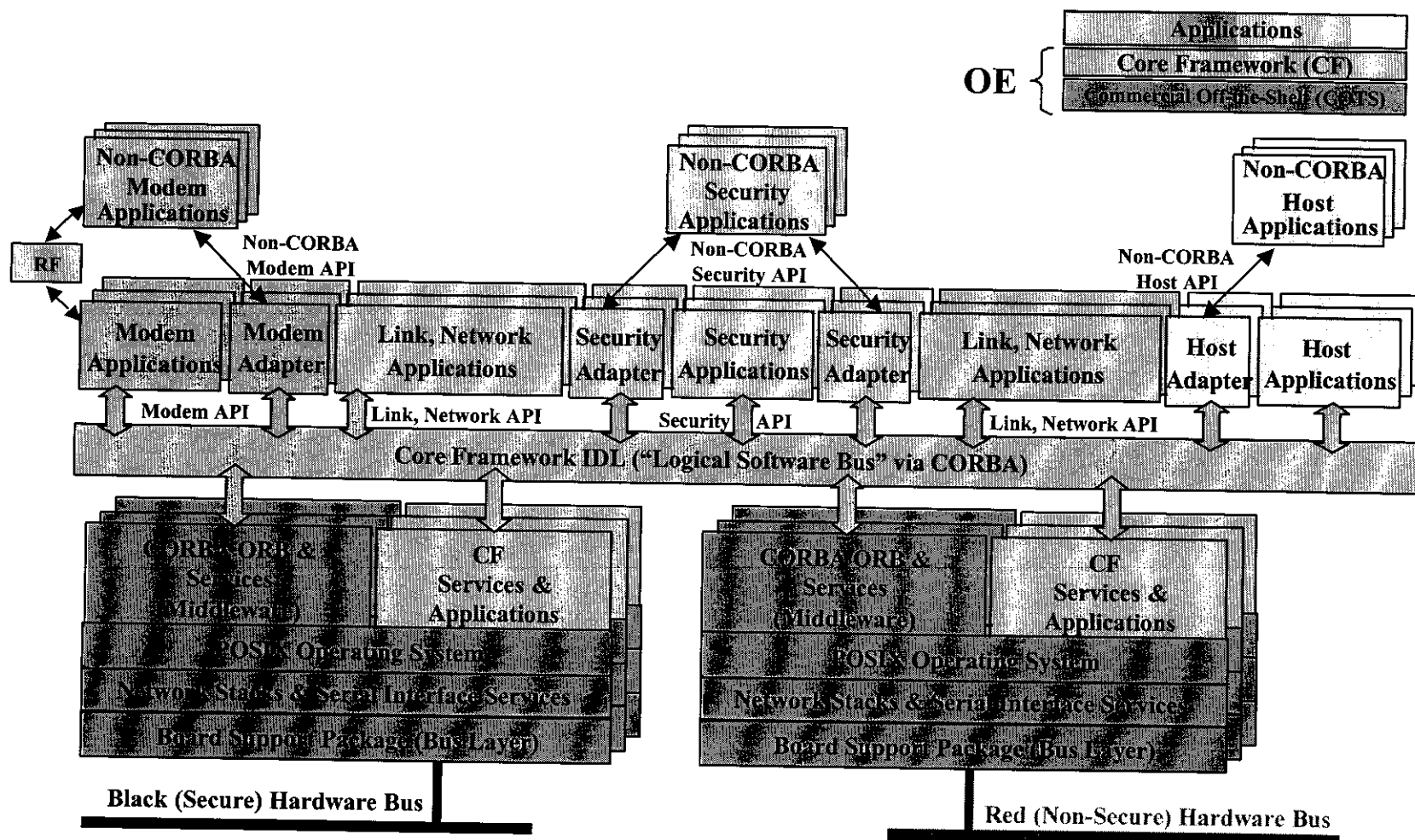
- **SDR Products and Technology are a Reality Today**
- **SDR Standards are Actively Being Worked today by Standards Bodies and Organizations**
- **Cognitive Radios have the Ability to Implement Protocols and Policies Beyond Traditional Communications.**
- **New Realms of Knowledge and Information Transfer are Achievable with Cognitive/SDR Radio as the Underlying Technology Enabler**

# Appendix

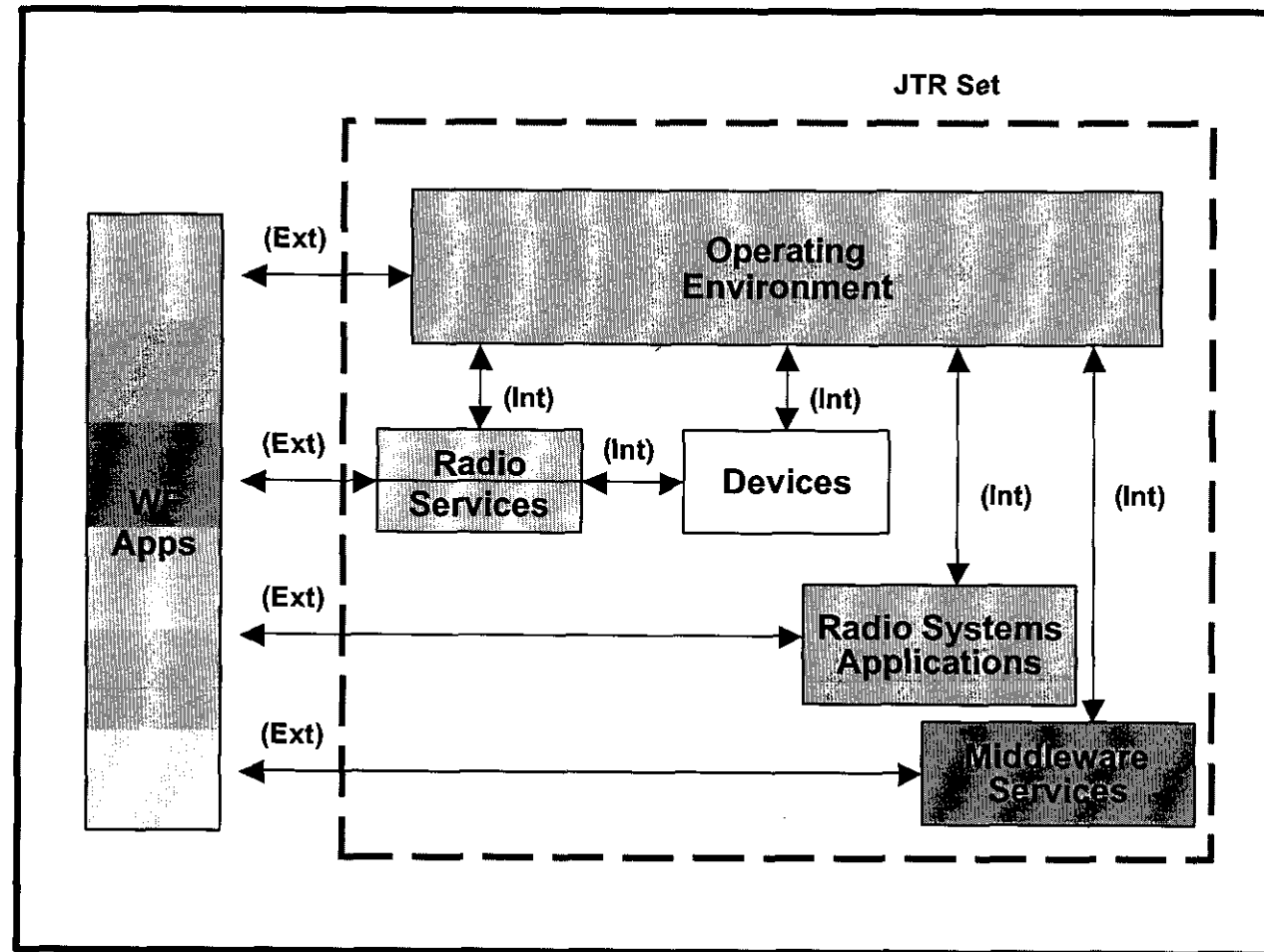
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- **SCA Reference Architecture**
- **Radio Services for Application Portability**
- **SDR Forum Standardized Hardware Architecture**
- **Reference Publications**

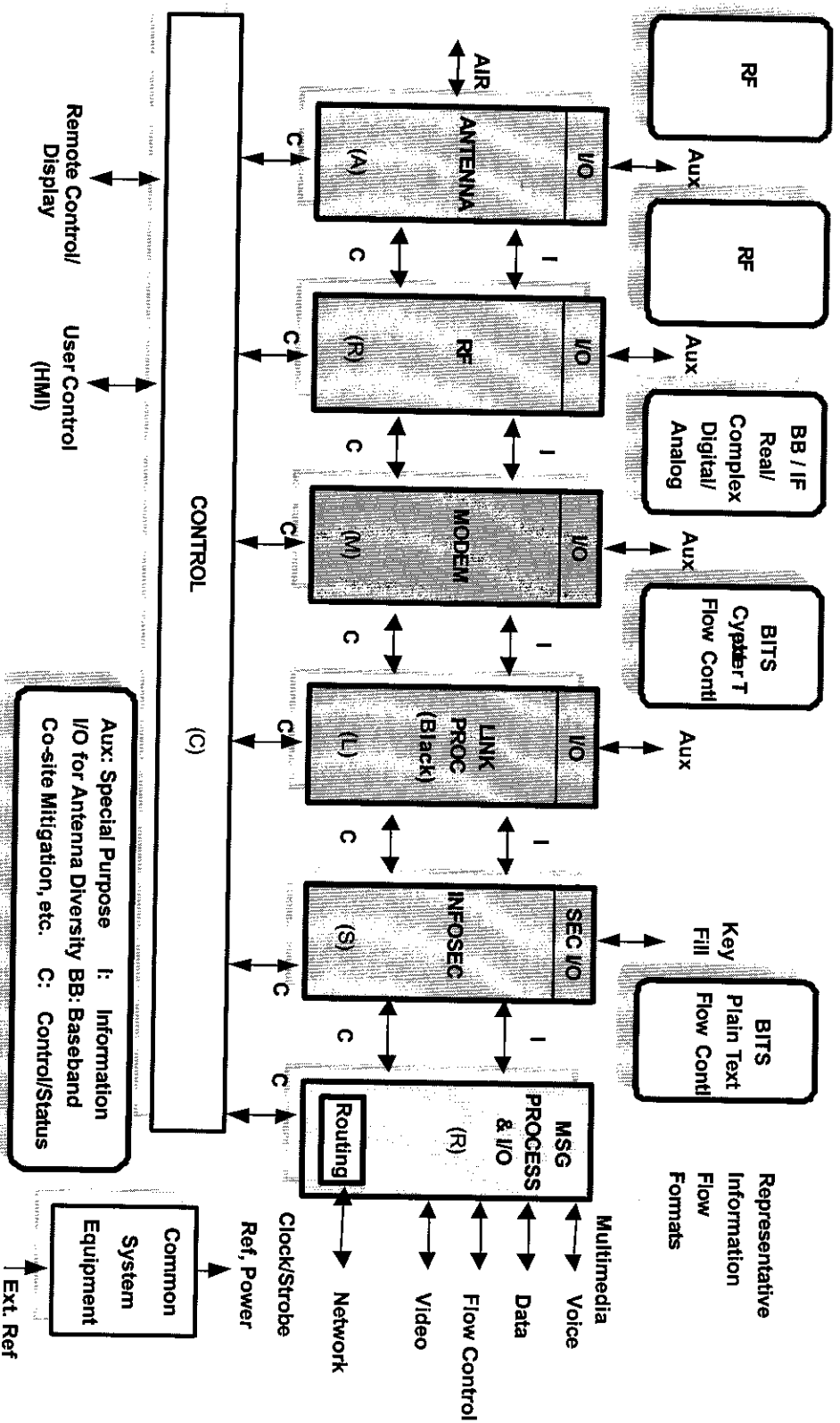
# SCA Reference Architecture



# Radio Services For Application Portability



# SDR Forum\* Standardized Hardware Architecture



**From Programmable Modular Communications System (PMCS) Guidance Document, 1997**  
 \*SDR Forum was established as an Industry Organization to address SDR technology on 1995

**GENERAL DYNAMICS**  
 Decision Systems

# Reference Publications

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- Mitola, "Cognitive Radio for Flexible Mobile Multimedia Communications", IEEE Mobile Multimedia Conference, 1999, pp3-10
- Mitola, "Future of Signal Processing - Cognitive Radio", Keynote, IEEE ICASSP, May 1999
- Mitola, Maguire, "Cognitive Radio: Making SW Radios More Personal", IEEE Personal Communications, August 1999, pp13-18
- Mitola, "SDR Architecture Refinement for JTRS", Milcom 2000, pp 214-218
- Mitola, "Software Radio Architecture: A Mathematical Perspective", IEEE J on Selected Areas in Comms, April 1999, pp 514-538
- Margulies, Mitola, "Software Defined Radio: A Technical Challenge and a Migration Strategy", 1998, pp551-556